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## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

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 2 Applicant..... Microsoft Corporation  
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 Title: Computer Graphics Methods and Apparatus For Ray Intersection

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TRANSMITTAL LETTER AND CERTIFICATE OF MAILING

5 To: Commissioner of Patents and Trademarks From: Lance R. Sadler (509) 324-9256  
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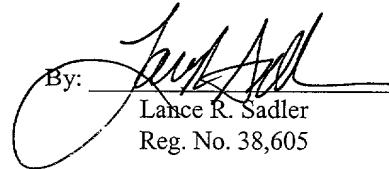
8

1. Transmittal Letter with Certificate of Mailing included.
2. PTO Return Postcard Receipt
3. New patent application (title page plus 31 pages, including claims 1-56 & Abstract)
4. Executed Declaration
5. 7 sheets of formal drawings (Figs. 1-12)
6. Assignment w/Recordation Cover Sheet

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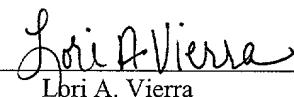
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

**Computer Graphics Methods and Apparatus For Ray  
Intersection**

Inventor(s):  
Steve Hollasch

ATTORNEY'S DOCKET NO. MS1-448US

1      **TECHNICAL FIELD**

2      This invention relates to computer graphics techniques and, more  
3      particularly, to apparatus and methods that optimize processing techniques to  
4      determine which of a number of shapes that approximate an object, and in  
5      particular approximate the surface of an object, have been intersected by a cast ray.

6

7      **BACKGROUND**

8      Computer graphics techniques typically involve manipulating computer-  
9      generated objects. Many techniques have evolved to assist in object manipulation,  
10     one of which typically represents or approximates an object and, in particular,  
11     approximates the surface of an object as collections of other smaller objects like  
12     polygons, e.g. triangles. That is, objects, some of which might have fairly  
13     complex surface characteristics, can be represented as collections of triangles that  
14     collectively represent or approximate the surface characteristics of the object.  
15     When object manipulation takes place, the manipulation operations are performed  
16     relative to the smaller shapes that approximate the surface of the object.

17     One technique that is used to manipulate objects is ray intersection. Ray  
18     intersection techniques can be used in a number of different scenarios that include  
19     image rendering, object selection, and surface interrogation (i.e. surface querying).

20     In image rendering, a ray can be directed from a visual point toward a  
21     picture element on a screen. Each object that is hit, or intersected, by the ray is set  
22     as an object to be drawn on the picture element to which the color of the object is  
23     allocated. This method of color processing the object can render effects of optical  
24     attributes, such as the reflection or the refraction of the object on the color of the  
25     object drawn on the screen by using the colors of the reflected ray from another

object or the refracted ray through another object. Therefore, this method can precisely express reflexes by the reflection or the refraction of other objects surrounding the intersected object.

Object selection involves operations where a user wants to directly manipulate a rendered image. For example, there may be a rendering of a scene that has particular objects in it. A user can click an object or a particular point on an object with a mouse, grab it, move it, and manipulate it. In this instance, the mouse click essentially casts a ray into the scene and determines the first object portion to be struck or intersected by the ray. Subsequent processing can take place based upon which objects are intersected by the ray.

Surface interrogation can involve an object moving through a rendered scene. In such applications, ray-intersection may be used to enable a determination as to which objects the moving object is about to collide with.

A majority of the processing that takes place in connection with ray-intersection concerns searching for an object that is intersected by a cast ray. Where, as here, the surface of objects are approximated by a plurality of shapes, e.g. triangles, conventional searching takes place by determining whether or not each and every shape that constitutes the approximated surface of an object is intercepted by the cast ray. For example, if the surface of an object is approximated by 6500 triangles, conventional searching algorithms test a first triangle to determine whether the cast ray intercepts it. If the first triangle is not intercepted by the cast ray, then the next triangle is tested and so on. Needless to say, processing each of the shapes used to approximate the surface of an object, while effective, is not the most optimal approach to the problem. Additional

1 background information can be found in the following U.S. Patents: 5,594,844,  
2 5,933,146, 5,313,568, 5,091,960, and 5,138,699.

3 Accordingly, this invention arose out of concerns associated with  
4 improving the apparatus and methods that are used in connection with computer  
5 graphics. In particular, the invention arose out of concerns associated with  
6 improving object-intersection processing techniques.

7

8 **SUMMARY**

9 Ray-intersection methods and apparatus that greatly facilitate computer  
10 graphics processing are described. In the described embodiment, a collection of  
11 shapes is first defined that approximates an object. The described shapes are  
12 polygons, with exemplary polygons comprising triangles. Various topologies can  
13 be used including triangle meshes, triangle strips, and triangle fans. A ray is cast  
14 toward the approximated object. A reference object which, in the illustrated  
15 example comprises a plane, is defined to contain the ray. Advantageously, the  
16 plane is selected to be parallel to one of the  $x$ ,  $y$ , and  $z$  axes which assists in  
17 reducing computational complexity.

18 With the plane and ray having been defined, aspects of the individual  
19 shapes are pre-characterized to provide characteristic data. In the illustrated  
20 example, pre-characterization takes place by testing each of the vertices of the  
21 polygons that make up the approximated object to ascertain their position relative  
22 to the reference object. With all of the vertices having been pre-characterized, the  
23 characteristic data is used to ascertain the position of the shapes relative to the  
24 reference object. This defines a sub-set of shapes that might be intersected by the  
25 ray. The sub-set of shapes is then evaluated to ascertain which of the shapes is

1 intersected by the ray. In other embodiments, the reference object can comprise  
2 more than one plane, e.g. two or more planes. Thus, each of the individual shapes  
3 that comprise a particular approximated object need not be individually tested for  
4 an intersection with the ray. Rather, only a sub-set of shapes that might be  
5 intersected by the ray are tested, with the other shapes having been ruled out based  
6 upon analysis of the characteristic data.

7

## 8 **BRIEF DESCRIPTION OF THE DRAWINGS**

9 Fig. 1 is an exemplary computer system that can be used to implement the  
10 described embodiment of the present invention.

11 Fig. 2 is a flow diagram that describes steps in a method in accordance with  
12 the described embodiment.

13 Fig. 3 is a diagrammatic representation of a ray, a reference object and a  
14 shape collection in accordance with the described embodiment of the present  
15 invention.

16 Fig. 4 is a diagram that illustrates an exemplary polygon topology known as  
17 a triangle mesh.

18 Fig. 5 is a diagram that illustrates an exemplary polygon topology known as  
19 a triangle strip.

20 Fig. 6 is a diagram that illustrates an exemplary polygon topology known as  
21 a triangle fan.

22 Fig. 7 is a diagram that illustrates the polygon topology of Fig. 4  
23 undergoing processing in accordance with the described embodiment of the  
24 present invention.

25

1 Fig. 8 is a diagram that illustrates the polygon topology of Fig. 7  
2 undergoing processing in accordance with the described embodiment.

3 Fig. 9 is a diagram that illustrates the polygon topology of Fig. 8  
4 undergoing processing in accordance with the described embodiment.

5 Fig. 10 is a diagram that illustrates the polygon topology of Fig. 9  
6 undergoing processing in accordance with the described embodiment.

7 Fig. 11 is a diagram that illustrates the polygon topology of Fig. 4  
8 undergoing processing in accordance with a described embodiment that is different  
9 from the embodiment of Figs. 7-10.

10 Fig. 12 is a diagram that illustrates the polygon topology of Fig. 11  
11 undergoing processing in accordance with the described embodiment.

12

13 **DETAILED DESCRIPTION**

14 **Exemplary Computer System**

15 Fig. 1 shows a general example of a computer 130 used to implement a  
16 computer graphic system in accordance with the described embodiment of the  
17 present invention.

18 Computer 130 includes one or more processors or processing units 132, a  
19 system memory 134, and a bus 136 that couples various system components  
20 including the system memory 134 to processors 132. Bus 136 represents one or  
21 more of any of several types of bus structures, including a memory bus or memory  
22 controller, a peripheral bus, an accelerated graphics port, and a processor or local  
23 bus using any of a variety of bus architectures. System memory 134 includes read  
24 only memory (ROM) 138 and random access memory (RAM) 140. A basic  
25 input/output system (BIOS) 142, containing the basic routines that help to transfer

1 information between elements within computer 130, such as during start-up, is  
2 stored in ROM 138.

3 Computer 130 further includes a hard disk drive 144 for reading from and  
4 writing to a hard disk (not shown); a magnetic disk drive 146 for reading from and  
5 writing to a removable magnetic disk 148; and an optical disk drive 150 for  
6 reading from or writing to a removable optical disk 152 such as a CD ROM or  
7 other optical media. Hard disk drive 144, magnetic disk drive 146, and optical  
8 disk drive 150 are connected to bus 136 by an SCSI interface 154 or some other  
9 appropriate interface. The drives and their associated computer-readable media  
10 provide nonvolatile storage of computer-readable instructions, data structures,  
11 program modules and other data for computer 130. Although the exemplary  
12 environment described herein employs a hard disk, a removable magnetic disk 148  
13 and a removable optical disk 152, it should be appreciated by those skilled in the  
14 art that other types of computer-readable media which can store data that is  
15 accessible by a computer, such as magnetic cassettes, flash memory cards, digital  
16 video disks, random access memories (RAMs), read only memories (ROMs), and  
17 the like, may also be used in the exemplary operating environment.

18 A number of program modules may be stored on hard disk 144, magnetic  
19 disk 148, optical disk 152, ROM 138, or RAM 140, including an operating system  
20 158, one or more application programs 160, other program modules 162, and  
21 program data 164. A user may enter commands and information into computer  
22 130 through input devices such as a keyboard 166 and a pointing device 168.  
23 Other input devices (not shown) may include, but not limited to, a microphone,  
24 joystick, game pad, satellite dish, scanner, or the like. These and other input  
25 devices are connected to the processing unit 132 through an interface 170 that is

1 coupled to the bus 136. A monitor 172 or other type of display device is also  
2 connected to the bus 136 via an interface, such as a video adapter 174. In addition  
3 to the monitor, personal computers typically include other peripheral output  
4 devices (not shown) such as speakers and printers.

5 Computer 130 commonly operates in a networked environment using  
6 logical connections to one or more remote computers, such as a remote computer  
7 176. Remote computer 176 may be another personal computer, a server, a router,  
8 a network PC, a peer device or other common network node, and typically  
9 includes many or all of the elements described above relative to computer 130,  
10 although only a memory storage device 178 has been illustrated in Fig. 1. The  
11 logical connections depicted in Fig. 1 include a local area network (LAN) 180 and  
12 a wide area network (WAN) 182. Such networking environments are  
13 commonplace in offices, enterprise-wide computer networks, intranets, and the  
14 Internet.

15 When used in a LAN networking environment, computer 130 is connected  
16 to the local network 180 through a network interface or adapter 184. When used  
17 in a WAN networking environment, computer 130 typically includes a modem 186  
18 or other means for establishing communications over wide area network 182, such  
19 as the Internet. Modem 186, which may be internal or external, is connected to  
20 bus 136 via a serial port interface 156. In a networked environment, program  
21 modules depicted relative to personal computer 130, or portions thereof, may be  
22 stored in the remote memory storage device. It will be appreciated by one of  
23 ordinary skill in the art that the network connections shown herein are exemplary  
24 and other means of establishing a communications link between the computers  
25 may be used.

Generally, the data processors of computer 130 are programmed by means of instructions stored at different times in the various computer-readable storage media of the computer. Programs and operating systems are typically distributed, for example, on floppy disks or CD-ROMs. From there, they are installed or loaded into the secondary memory of a computer. At execution, they are loaded at least partially into the computer's primary electronic memory. The invention described herein includes these and other various types of computer-readable storage media when such media contains instructions or programs for implementing the steps described below in conjunction with a microprocessor or other data processor. The present invention also includes the computer itself when programmed according to the methods and techniques described below.

For purposes of illustration, programs and other executable program components such as the operating system are illustrated herein as discrete blocks, although it is recognized that such programs and components reside at various times in different storage components of the computer, and are executed by the data processor(s) of the computer.

## Overview

Conventional algorithms that evaluate objects by approximating the object with shapes, e.g. approximating the surface of an object as formed by a plurality of shapes, typically test each individual shape to determine whether a cast ray intersects with a given shape. Exemplary conventional intersection algorithms are described in the following publications: (1) *An Introduction to Ray Tracing*, Andrew Glassner, ISBN 0-12-286160-4, section 3.2, *Polygon Intersection*; (2) *Real-Time Rendering*, Tomas Moller and Eric Haines, ISBN 1-56881-101-2,

1 section 10.5, *Ray/Triangle Intersection*; (3) *Graphics Gems I*, edited by Andrew  
2 Glassner, ISBN 0-12-286165-5, pp 390-393, *An Efficient Ray-Polygon*  
3 *Intersection*, and p 394, *Fast Ray-Polygon Intersection*; and (4) *Graphics Gems II*,  
4 edited by James Arvo, ISBN 0-12-064480-0, pp 257-263, *Ray-Triangle*  
5 *Intersection Using Binary Recursive Subdivision*.

6 In the described embodiment, the total number of shapes that are typically  
7 evaluated by the conventional algorithms for an intersection are significantly  
8 reduced prior to evaluation. This reduction of the number of shapes to be  
9 evaluated is achieved by pre-characterizing aspects of the individual shapes that  
10 make up an object. Through the illustrated and described pre-characterization  
11 processing, a sub-set of possible intersected shapes, which has a smaller number of  
12 shapes than the total number of shapes that approximate the surface of the object,  
13 is defined, with such sub-set being subsequently evaluated to ascertain those  
14 shapes within the sub-set that are intersected by the defined ray. Reducing the  
15 number of shapes that are evaluated for ray intersections greatly reduces the  
16 processing overhead thereby improving processing times. Improvements over  
17 conventional processing techniques have been observed on the order of 5- to 10-  
18 times faster.

19

20 **Exemplary Method**

21 Fig. 2 shows a flow diagram that describes processing steps in a ray-  
22 intersection method in accordance with the described embodiment. The steps  
23 depicted in Fig. 2 can be implemented in any suitable software, hardware, or  
24 firmware. Fig. 3, which will be used in connection with the description of Fig. 2,  
25 diagrammatically depicts aspects of the processing described by Fig. 2.

1 As shown, a collection of shapes is first defined to approximate an object in  
2 connection with a computer graphics program. In this example, the surface of the  
3 object is approximated by a collection of shapes. Fig. 3 shows an exemplary  
4 portion of such a collection generally at 300. Any suitable shapes can be used. In  
5 the described embodiment, the shapes have a similar geometry. Typically,  
6 polygons having a plurality of vertices are used. As will become apparent below,  
7 it is advantageous to select polygons that collectively have more faces than  
8 vertices when approximating the surface of an object. In the illustrated example,  
9 the polygons comprise triangles.

10 As shown in Fig. 3, there are four depicted triangles, 302, 304, 306, and  
11 308 having the vertices V<sub>1</sub>-V<sub>7</sub> as indicated. There can be many thousands of  
12 triangles used to approximate the surface of an object. Additionally, the collection  
13 of triangles can be arranged to have different topologies. Exemplary topologies  
14 are shown in Figs. 4-6. Specifically, Fig. 4 shows a topology known as a triangle  
15 mesh; Fig. 5 shows a topology known as a triangle strip; and Fig. 6 shows a  
16 topology known as a triangle fan. The collection of triangles can be arranged so  
17 that some of them share a side and/or vertices. For example, in Fig. 3, triangles  
18 302 and 304 share a vertex, while triangles 304 and 306 share a side and two  
19 vertices. Other collections can be defined where none of the triangles share a  
20 vertex. Although triangles are depicted in the illustrated and described  
21 embodiment, it is to be understood that other shapes or polygons can be used to  
22 approximate an object.

23 Step 200 (Fig. 2) defines a ray (Fig. 3) that is cast toward the approximated  
24 object. The ray can be cast in any suitable manner using conventional ray-  
25 intersection techniques. Here, a ray (Fig. 3) is seen to extend toward and through

1 collection 300. Step 210 defines at least one reference object relative to the  
2 approximated object. The reference object is defined in such a way that it contains  
3 at least a portion of the ray. In the illustrated and described embodiment, the  
4 reference object comprises a plane (Fig. 3), and the plane contains the entirety of  
5 the ray. In the described embodiment, a plane that is parallel to one of the  $x$ ,  $y$ , and  
6  $z$  axes is selected to reduce the processing complexity as will be described just  
7 below.

8 Specifically, a plane can be represented by the following equation:

9

$$10 \quad Ax + By + Cz + D = 0$$

11 Here,  $x$ ,  $y$ , and  $z$  represent some point for which there is a real value. The  
12 real value for the point increases positively as the point is moved in a positive  
13 direction away from the plane. Similarly, the real value for the point increases  
14 negatively as the point is moved in a negative direction away from the plane.

15 In the described embodiment, by selecting the plane such that it is parallel  
16 to one of the above-mentioned axes (here, the  $z$  axis),  $z=0$  and the equation is  
17 simplified as follows:

18

$$19 \quad Ax + By + D = 0$$

20 This optimization results in one less addition and one less multiply  
21 operation, which reduces the processing complexity.

22 Step 212 pre-characterizes aspects of the individual shapes that comprise  
23 the collection of shapes to provide characteristic data. In the illustrated and  
24 described embodiment, pre-characterization identifies positional aspects of sub-  
25 components of the individual shapes. The sub-components in this example

1 comprise the vertices of the triangles. Specifically, the position of each vertex is  
2 computed relative to the plane by simply evaluating the equation immediately  
3 above. The following table sets forth the outcome of the evaluation for each  
4 vertex:

Equation Result	Position Relative To Plane
$Ax + By + D = 0$	On the plane.
$Ax + By + D < 0$	Negative side of the plane.
$Ax + By + D > 0$	Positive side of the plane.

11 Here, depending on the coordinates of the particular vertex, the evaluation  
12 of the equation will ascertain where the vertex is positioned relative to the plane.  
13 That is, if the equation evaluates to zero, then the vertex is on the plane.  
14 Alternatively, if the equation evaluates to less than or greater than zero, the vertex  
15 is on the negative side or positive side of the plane, respectively. In the Fig. 3  
16 example, evaluation of the illustrated vertices will give the following results set  
17 forth in the table below:

Equation Result	Position Relative To Plane
$V_1 < 0$	Negative side of plane.
$V_2 < 0$	Negative side of plane.
$V_3 = 0$	On the plane.
$V_4 > 0$	Positive side of plane.
$V_5 > 0$	Positive side of plane.

1	$V_6 > 0$	Positive side of plane.
2	$V_7 > 0$	Positive side of plane.

3  
4 This evaluation is set forth in pseudo code as follows:

```
5
6     Boolean      vflags [nVertices]
7     For i in [0, nVertices)
8         If (A * vertices [i]_x + B * vertices [i]_y + D) >0
9             Vflag[i] ←true
10            Else
11                Vflag[i] ←false
```

9  
10 Essentially, this routine loops through each vertex flagging it as “true” if it  
11 is on the positive side of the plane, or flagging it as false if it is on the negative  
12 side of the plane. For purposes of the analysis and evaluation of the shapes  
13 discussed below, a point that is on the plane can be considered as being either on  
14 the positive or the negative side of the plane, as long as consistency is maintained  
15 throughout the evaluation.

15 With the pre-characterization processing having been done as described  
16 above, step 214 uses the characteristic data to ascertain the position of a shape  
17 relative to the reference object. This step determines whether or not a particular  
18 individual shape has a chance of being intersected by the ray. In this manner, a  
19 sub-set of shapes that might be intersected by the ray is defined by determining  
20 which of the shapes satisfies a predefined relationship relative to the reference  
21 object, i.e. plane. Using the above example, the following is ascertained. If a  
22 shape’s vertices are all on one side or the other of the reference object, here the  
23 Fig. 3 plane, then it is impossible for the ray (which lies in the plane) to intersect  
24 the shape. Accordingly, these shapes can be immediately discarded. If, on the  
25

other hand, a shape's vertices lie on both sides of the plane, then the object is said to "straddle" the plane. If this is the case, then the shape might be, but is not necessarily, intersected by the ray (e.g. the shape might straddle the plane, but be located entirely above or below the ray). This evaluation is set forth as steps 214 through 220. There, step 214 uses the characteristic data to ascertain the position of a shape relative to the reference object. This step determines whether a shape is on the negative side of, positive side of, or straddles the plane. Step 216 determines whether a particular shape meets position criteria. In this example, the position criteria assists in defining a sub-set of shapes that straddle the plane. If position criteria is met, then step 218 adds the shape to a list of shapes that are to be evaluated for intersection. If the position criteria is not met, or if the shape was added to the list of shapes for evaluation, step 220 then determines whether there are any additional shapes to evaluate. If there are, then the method loops back to step 216 and evaluates the next shape. If there are no additional shapes to evaluate, then step 222 evaluates the shapes that are on the list to ascertain whether the cast ray intersects one or more of the shapes. The intersection processing of step 222 can take place through the use of conventionally known techniques.

As an example, consider Fig. 3 again and assume that the adopted convention will consider vertices that lie on the plane to be on the positive side of the plane. Evaluation of all of the vertices indicates that only triangle 302 "straddles" the plane. In this case, the position criteria (i.e. does the shape straddle the plane?) is met. Hence, triangle 302 is added to the list of shapes that is to be evaluated (step 218) and step 220 determines whether there are any additional shapes to evaluate. Processing then takes place as described above.

1       Exemplary pseudo code that sets forth one way of accomplishing this task  
2       is set forth as follows:

```
3       For i in [0, nTriangles)
4           If (Vflag[tri[i][0] = Vflag[tri[i][1]])
5              And
6              (Vflag[tri[i][1] = Vflag[tri[i][2]])
7              Skip to next i
8
9           If StandardIntersect (tri[i][0], tri[i][1], tri[i][2])
10             Return TRUE
```

11       What this code does is loop through each of the flags for the vertices of a  
12       shape to determine whether the vertices are all equal. For example, if all of the  
13       flags for a vertex are true or false, then the shape can be discarded and the code  
14       skips to the next  $i$  or shape. If, on the other hand, some of the flags are true and  
15       other of the flags are false, then the code executes a “StandardIntersect” algorithm,  
16       which determines whether or not there is an intersection. If there is an intersection  
17       between the ray and the shape, then the code returns a value indicating that this is  
18       the case. In this case, advantageously, the inventive processing rules out many of  
19       the shapes prior to using an intersect algorithm to ascertain whether or not there is  
20       an intersection between the ray and one or more shapes.

### 18       Example

19       As a further example, consider Figs. 7-10. Fig. 7 shows a collection of  
20       shapes 400 that comprise a triangle mesh approximating an object of interest.  
21       Although this example is described in the context of a triangle mesh, it will be  
22       apparent to those of skill in the art, that the evaluation described just below can be  
23       conducted in connection with other topologies, examples of which are given  
24       above. In this particular example, the collection constitutes 60 surfaces (each  
25

triangle comprising one surface) and 42 vertices. In the past, intersection algorithms have evaluated each of the separate triangles of the illustrated collection to determine whether there is an intersection with a cast ray. So, in this case, conventional methods might have started with the first triangle in the first column, evaluated it for an intersection, and then discarded it when there was no intersection. This method would then step through each of the triangles, similarly evaluating them for an intersection with the ray. With complex surfaces having a high degree of resolution (i.e. many shapes), processing overhead can be quite large. Advantageously, the described embodiment reduces the number of shapes that must be tested for an intersection. This saves greatly on processing overhead and increases the speed with which objects are processed.

Fig. 7 shows a ray that has been cast toward the object that is approximated by collection 400. The ray extends into and out of the plane of the page upon which Fig. 7 appears. Fig. 8 shows a plane containing the ray that is perpendicular to the page upon which Figures 7 and 8 appear. Fig. 9 shows a sub-set of shapes (shaded for clarity) that might be intersected by the ray. Here, an evaluation has been performed to determine whether the triangle(s) that are defined by the individual vertices straddle the defined plane. If they do straddle the defined plane, then it is possible that they are intersected by the ray. Here, the number of triangles that have to be evaluated by an intersection algorithm have been reduced from 60 to 10.

Fig. 10 shows collection 400 after the intersection algorithm has been run on all of the triangles in the shaded sub-set of Fig. 9. In this example, only one triangle (shaded for clarity) is intersected by the ray.

1            **Multiple Plane Embodiment**

2            In another embodiment, multiple planes are used to further reduce the sub-  
3            set of shapes that need to be evaluated by an intersection algorithm.

4            Fig. 11 shows collection 400 at a processing point that is the same shown in  
5            Fig. 9. Fig. 11, however, illustrates a second plane defined to contain the ray and  
6            perpendicular to the first plane. It should be understood that the second plane does  
7            not have to be perpendicular to the first plane, but may in fact intersect the first  
8            plane in any direction orthogonal to the first plane. At this point, the shapes have  
9            been evaluated to determine whether they straddle the first plane. This has  
10          produced the illustrated shaded sub-set. Fig. 12 shows an exemplary subset after  
11          the shapes of the Fig. 11 sub-set have been evaluated to determine whether they  
12          straddle the second plane. In this case, the triangles that need to be evaluated by  
13          the intersection algorithm have been reduced from 60 to two. Of course, as should  
14          be apparent to one of ordinary skill in the art, more than two reference objects  
15          may be used for purposes of further paring down the number of shapes that need  
16          to be evaluated.

17          The inventive methods and apparatus greatly facilitate computer graphics  
18          processing by reducing processing complexities associated with ray-intersection.  
19          Advancements are achieved by reducing the number of shapes in a collection that  
20          must be evaluated for ray intersection. The described embodiment achieves its  
21          processing advances by recognizing that aspects of the shapes can be pre-  
22          processed prior to subjecting them to intersection processing. The selected aspects  
23          in the described embodiment are the vertices of the polygons that comprise the  
24          collection. By pre-characterizing the vertices of the polygons, certain polygons  
25          are ruled out before they are processed by an intersection algorithm.

1        Although the invention has been described in language specific to structural  
2        features and/or methodological steps, it is to be understood that the invention  
3        defined in the appended claims is not necessarily limited to the specific features or  
4        steps described. Rather, the specific features and steps are disclosed as preferred  
5        forms of implementing the claimed invention.

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1      **CLAIMS**

2      1. In a computer graphic processing system in which a ray is cast toward  
3      an object represented by a collection of pre-determined shapes each characterized  
4      by characteristic data, a method for determining which of the shapes are  
5      intersected by the ray, the method comprising:

6              defining a reference object relative to the represented object;

7              determining the positions of the shapes relative to the reference object  
8      using the characteristic data; and

9              determining, on the basis of the positions of the shapes relative to the  
10     reference object, those shapes that have no chance of intersecting the ray, and  
11     those remaining shapes that may intersect the ray.

12  
13      2. The method of claim 1 further comprising using a predetermined  
14     algorithm to determine which one of those remaining shapes intersects the ray.

15  
16      3. The method of claim 1, wherein the collection of shapes comprises at  
17     least one polygonal shape.

18  
19      4. The method of claim 1, wherein the collection of shapes comprises a  
20     plurality of polygonal shapes.

21  
22      5. The method of claim 1, wherein the collection of shapes comprises at  
23     least one triangle.

1       **6.**     The method of claim 1, wherein the collection of shapes comprises a  
2     plurality of triangles.  
3

4       **7.**     The method of claim 1, wherein the collection of shapes comprises a  
5     triangle mesh.  
6

7       **8.**     The method of claim 1, wherein the collection of shapes comprises a  
8     triangle strip.  
9

10      **9.**     The method of claim 1, wherein the collection of shapes comprises a  
11     triangle fan.  
12

13      **10.**    The method of claim 1, wherein said reference object comprises at  
14     least one plane.  
15

16      **11.**    The method of claim 1, wherein said reference object comprises a  
17     plurality of planes each of which contain the ray.  
18

19      **12.**    The method of claim 1, wherein said determining the positions of  
20     the shapes comprises determining positional aspects of sub-components of  
21     individual ones of the shapes to provide the characteristic data.  
22

1           **13.** The method of claim 12, wherein the individual shapes comprise  
2 polygons and the sub-components comprise vertices that define the polygons, said  
3 determining the positions of the shapes comprising computing the positions of the  
4 vertices relative to the reference object.

5

6           **14.** The method of claim 13, wherein the reference object comprises a  
7 plane.

8

9           **15.** The method of claim 14, wherein the plane is parallel to one of the  
10  $x$ ,  $y$ , and  $z$  axes.

11

12           **16.** In a computer graphic processing system in which a ray is cast  
13 toward an object represented by a collection of pre-determined shapes, a method  
14 for determining which of the shapes are intersected by the ray, the method  
15 comprising:

16                 defining a collection of polygons that approximate an object, individual  
17 polygons having a plurality of vertices;

18                 casting a ray toward the approximated object;

19                 defining a reference object relative to the collection of polygons and that  
20 contains the cast ray;

21                 pre-characterizing at least some vertices of at least some of the polygons to  
22 provide characteristic data that describes the vertices' positions relative to the  
23 reference object; and

24                 using the characteristic data to ascertain the positions of the individual  
25 polygons relative to the reference object.

1  
2       **17.** The method of claim 16, wherein the collection of polygons  
3 approximate the surface of the object.  
4

5       **18.** The method of claim 16, wherein the individual polygons have a  
6 similar geometry.  
7

8       **19.** The method of claim 16, wherein the individual polygons comprise  
9 triangles.  
10

11       **20.** The method of claim 16, wherein the collection of polygons has a  
12 plurality of faces and a plurality of vertices, said faces outnumbering said vertices.  
13

14       **21.** The method of claim 16, wherein at least two of said polygons share  
15 at least one side.  
16

17       **22.** The method of claim 16, wherein at least two of said polygons share  
18 at least one vertex.  
19

20       **23.** The method of claim 16, wherein none of said polygons share a  
21 vertex.  
22  
23  
24  
25

1           **24.** The method of claim 16, wherein said using of the characteristic  
2 data comprises determining whether an individual polygon is in a sub-set of  
3 polygons that might be intersected by the ray.

4

5           **25.** The method of claim 16, wherein said using of the characteristic  
6 data comprises determining whether an individual polygon is in a sub-set of  
7 polygons at least some of which straddle the reference object.

8

9           **26.** The method of claim 16, wherein said using of the characteristic  
10 data comprises determining whether an individual polygon is in a sub-set of  
11 polygons at least some of which straddle the reference object, and further  
12 comprising evaluating the sub-set of polygons to determine which polygons are  
13 intersected by the ray.

14

15           **27.** In a computer graphic processing system in which a ray is cast  
16 toward an object represented by a collection of pre-determined shapes, a method  
17 for determining which of the shapes are intersected by the ray, the method  
18 comprising:

19                 defining a plurality of triangles that approximate an object, individual  
20 triangles having three vertices;

21                 casting a ray toward the approximated object;

22                 defining at least one plane relative to the approximated object to contain the  
23 ray;

1            pre-characterizing the vertices of the plurality of triangles to provide  
2            characteristic data that describes the positions of the vertices relative to said at  
3            least one plane; and

4            using the characteristic data to ascertain the positions of the individual  
5            triangles relative to said at least one plane.

6

7            **28.**        The method of claim 27, wherein said defining of said plurality of  
8            triangles comprises defining a triangle mesh.

9

10          **29.**        The method of claim 27, wherein said defining of said plurality of  
11          triangles comprises defining a triangle fan.

12

13          **30.**        The method of claim 27, wherein said defining of said plurality of  
14          triangles comprises defining a triangle strip.

15

16          **31.**        The method of claim 27, wherein said using of the characteristic  
17          data comprises determining whether a particular individual triangle has a chance  
18          of being intersected by the ray.

19

20          **32.**        The method of claim 27, wherein said using of the characteristic  
21          data comprises determining whether a particular individual triangle straddles said  
22          at least one plane.

1           **33.** The method of claim 27, wherein said using of the characteristic  
2 data comprises defining a sub-set of triangles at least some of which straddle the  
3 plane, and further comprising evaluating the sub-set of triangles to ascertain which  
4 triangles are intersected by the ray.

5

6           **34.** The method of claim 27, wherein none of the triangles share any  
7 vertices.

8

9           **35.** The method of claim 27, wherein all of the triangles share at least  
10 one vertex with another of the triangles.

11

12           **36.** The method of claim 27, wherein said defining of said at least one  
13 plane comprises defining a plane to be parallel to one of the  $x$ ,  $y$ , or  $z$  axes.

14

15           **37.** In a computer graphic processing system in which a ray is cast  
16 toward an object represented by a collection of pre-determined polygons, a method  
17 for determining which of the polygons are intersected by the ray, the method  
18 comprising:

19           defining a sub-set of polygons from a collection of polygons that  
20 approximate an object by determining which polygons have vertices that satisfy a  
21 predefined relationship relative to a reference object; and

22           evaluating the sub-set of polygons to ascertain which of the polygons is  
23 intersected by a cast ray.

1           **38.** The method of claim 37, wherein the reference object comprises a  
2 plane.  
3

4           **39.** The method of claim 37, wherein the reference object comprises  
5 multiple planes.  
6

7           **40.** The method of claim 37, wherein the reference object comprises a  
8 plane, and said determining comprises determining which polygons straddle the  
9 plane.  
10

11          **41.** One or more computer-readable media having computer-readable  
12 instructions thereon which, when executed by a computer, implement the method  
13 of claim 37.  
14

15          **42.** A programmable computer having a memory and a processor, the  
16 memory containing software code which causes the processor to execute the  
17 method of claim 37.  
18

19          **43.** A computer graphic processing system comprising a programmable  
20 computer programmed with computer-readable instructions which, when executed  
21 by the programmable computer, implement the following method:  
22

23              defining a plurality of polygons that approximate an object, individual  
24 polygons having a plurality of vertices;  
25

26              casting a ray toward the approximated object;

1 defining at least one plane relative to the approximated object to contain the  
2 ray;

3 pre-characterizing the vertices of the plurality of polygons to provide  
4 characteristic data that describes the positions of the vertices relative to said at  
5 least one plane;

6 using the characteristic data to ascertain the positions of the individual  
7 polygons relative to said at least one plane;

8 determining which of the individual polygons might be intersected by the  
9 ray, based upon their ascertained positions, to provide a sub-set of polygons; and

10 evaluating the sub-set of polygons to ascertain which of the polygons are  
11 intersected by the ray.

12  
13 **44.** The computer graphic processing system of claim 43, wherein said  
14 defining of the plurality of polygons comprises defining a polygon mesh.

15  
16 **45.** The computer graphic processing system of claim 43, wherein said  
17 defining of the plurality of polygons comprises defining a polygon fan.

18  
19 **46.** The computer graphic processing system of claim 43, wherein said  
20 defining of the plurality of polygons comprises defining a polygon strip.

21  
22 **47.** The computer graphic processing system of claim 43, wherein said  
23 defining of said at least one plane comprises defining said plane to be parallel to  
24 one of the x, y, and z axes.

1       **48.** One or more computer-readable media having computer-readable  
2 instructions thereon which, when executed by a computer graphic processing  
3 system, implement the following method:

4             defining a plurality of triangles that approximate an object, individual  
5 triangles having three vertices;

6             casting a ray toward the approximated object;

7             defining at least one plane relative to the approximated object to contain the  
8 ray;

9             pre-characterizing the vertices of the plurality of triangles to provide  
10 characteristic data that describes the positions of the vertices relative to said at  
11 least one plane;

12             using the characteristic data to ascertain the positions of the individual  
13 triangles relative to said at least one plane;

14             determining which of the individual triangles might be intersected by the  
15 ray, based upon their ascertained positions, to provide a sub-set of triangles; and

16             evaluating the sub-set of triangles to ascertain which of the triangles are  
17 intersected by the ray.

18  
19       **49.** The one or more computer-readable media of claim 48, wherein said  
20 defining of the plurality of triangles comprises defining one of a triangle mesh, a  
21 triangle strip, and a triangle fan.

22  
23       **50.** A computer graphic processing system comprising:

24             a processor;

25             memory; and

1 software code stored in the memory that causes the processor to implement  
2 a ray-intersection algorithm which:

- 3 casts a ray at a collection of shapes that approximate an object;
- 4 defines a reference object that contains the ray;
- 5 pre-characterizes aspects of individual ones of the shapes of the  
collection to provide characteristic data; and
- 6 uses the characteristic data to ascertain the position of the shapes of  
the collection of shapes relative to the reference object.

9

10 51. The computer graphic processing system of claim 50, wherein the  
11 ray intersection algorithm casts a ray at a collection of polygons, each of which  
12 have similar geometries.

13

14 52. The computer graphic processing system of claim 50, wherein the  
15 ray intersection algorithm casts a ray at a collection of triangles.

16

17 53. The computer graphic processing system of claim 52, wherein the  
18 collection of triangles defines a triangle mesh.

19

20 54. The computer graphic processing system of claim 50, wherein the  
21 ray intersection algorithm pre-characterizes aspects of the shapes by computing  
22 positions of various sub-components of the shapes relative to the reference object.

1           **55.** The computer graphic processing system of claim 54, wherein the  
2 reference object comprises at least one plane.  
3

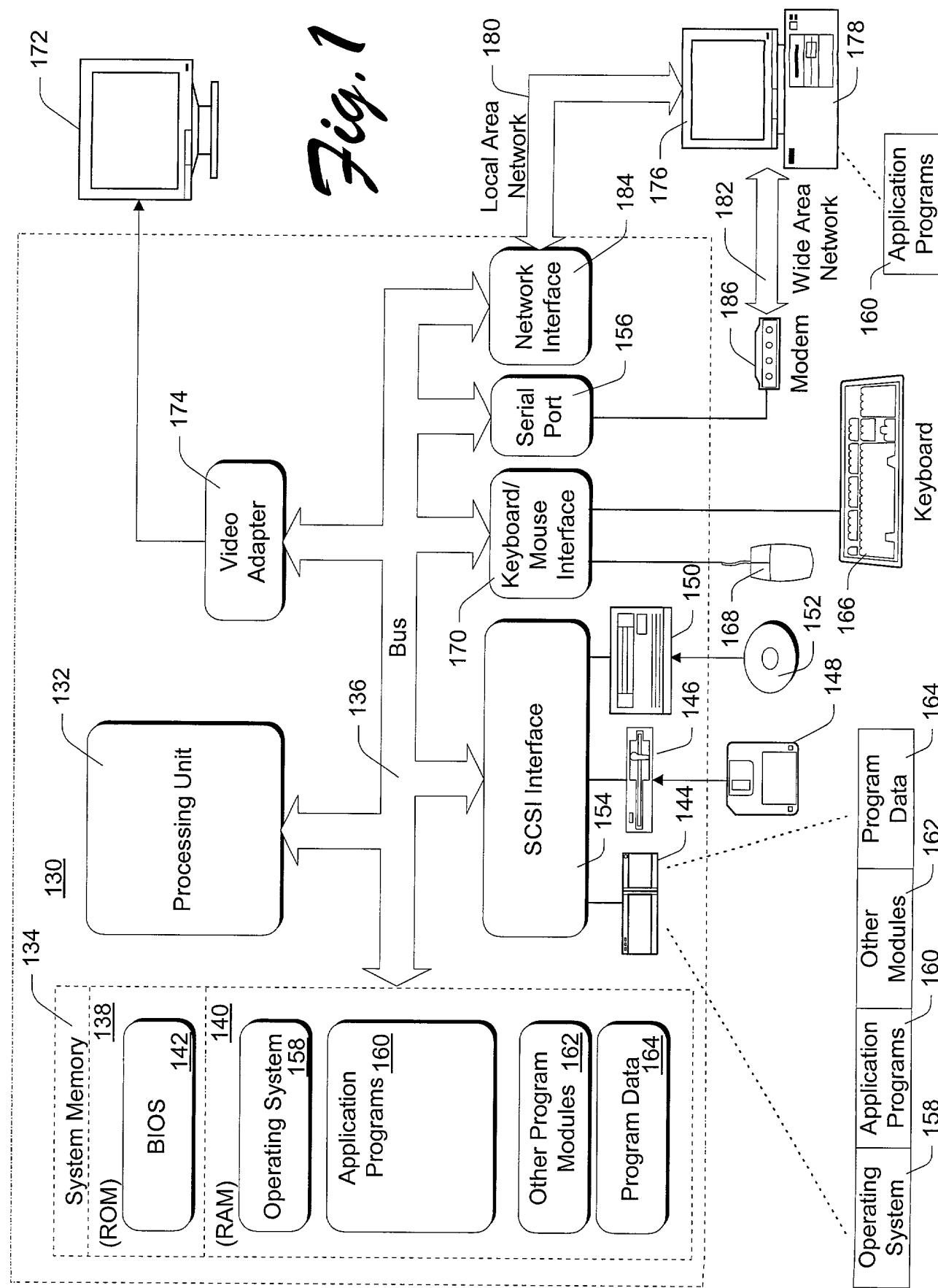
4           **56.** The computer graphic processing system of claim 55, wherein the  
5 shapes comprise polygons and the sub-components comprise vertices of the  
6 polygons.  
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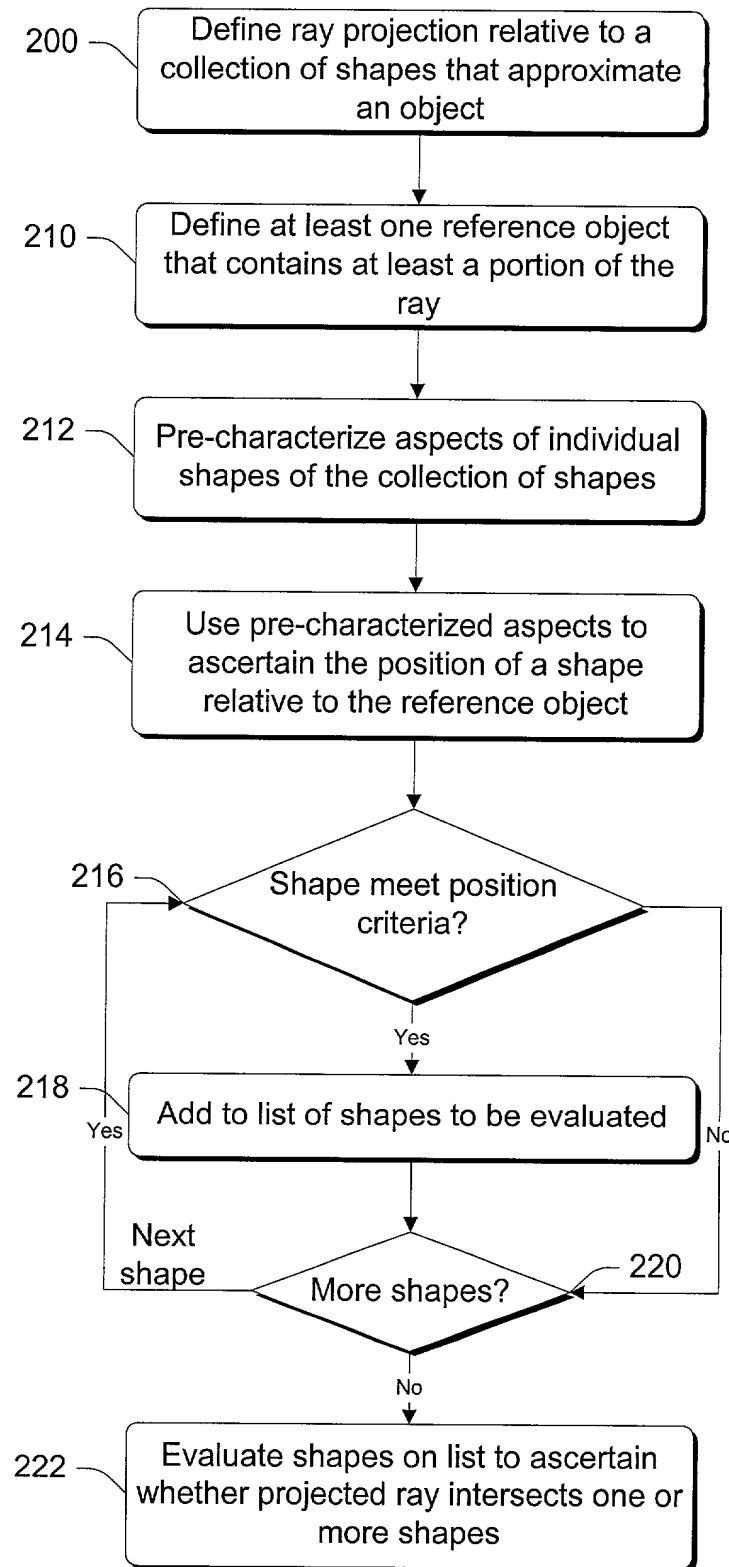
1      **ABSTRACT**

2      Ray-intersection methods and apparatus that greatly facilitate processing  
3      associated with computer graphics are described. In the described embodiment, a  
4      collection of shapes are defined that approximate an object. The described shapes  
5      are polygons, with exemplary polygons comprising triangles. A ray is cast toward  
6      the approximated object, and a reference object which, in the described  
7      embodiment comprises one or more planes, is defined to contain the ray. Aspects  
8      of the individual shapes are pre-characterized to provide characteristic data. In the  
9      described embodiment, pre-characterization takes place by testing each of the  
10     vertices of the polygons to ascertain their position relative to the reference object.  
11     The characteristic data is then used to ascertain the position of the shapes that are  
12     defined by the vertices, relative to the reference object. This provides a sub-set of  
13     shapes that might be intersected by the ray. The sub-set of shapes is then  
14     evaluated to ascertain which of the shapes is intersected by the ray.

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Fig. 1



*Fig. 2*

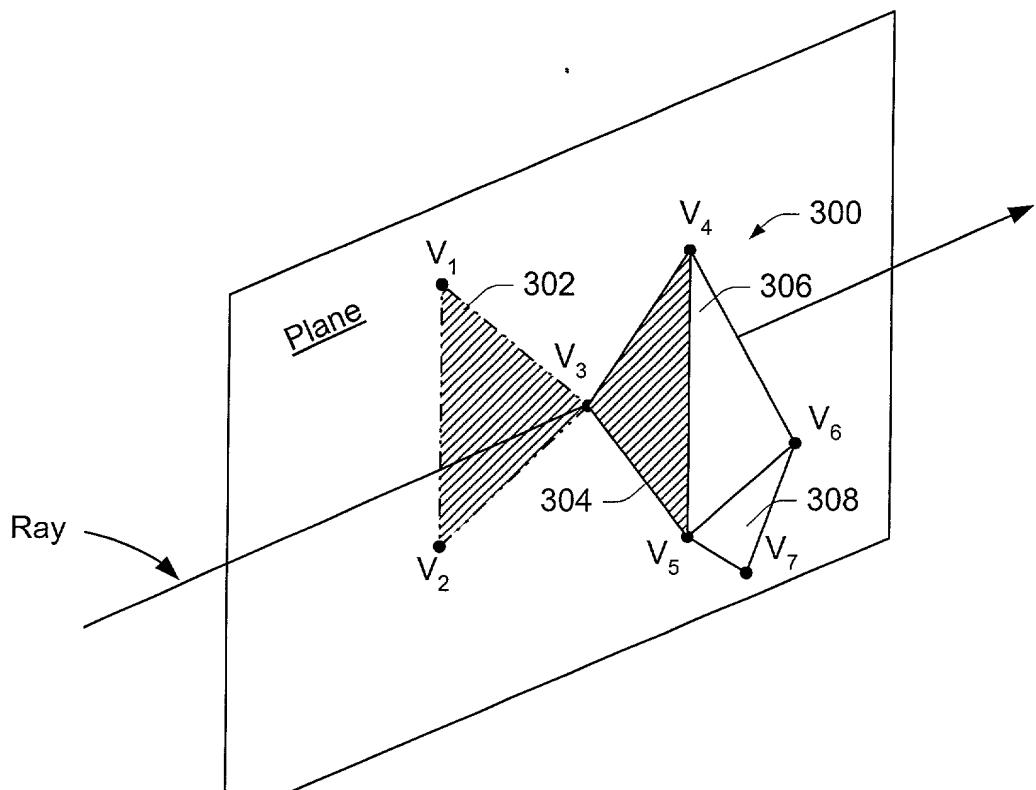


Fig. 3

Tri-mesh

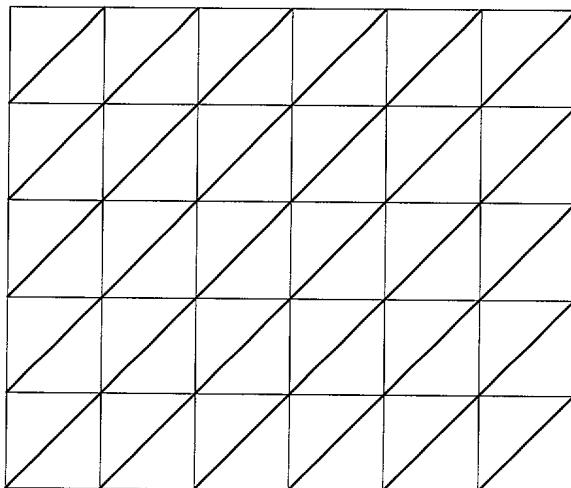


Fig. 4

Tri-strip

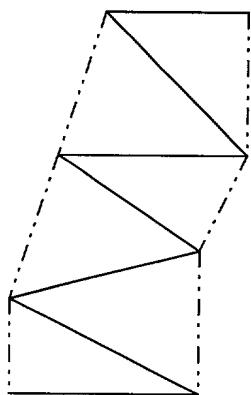


Fig. 5

Tri-fan

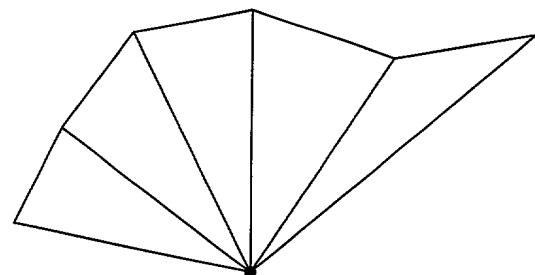


Fig. 6

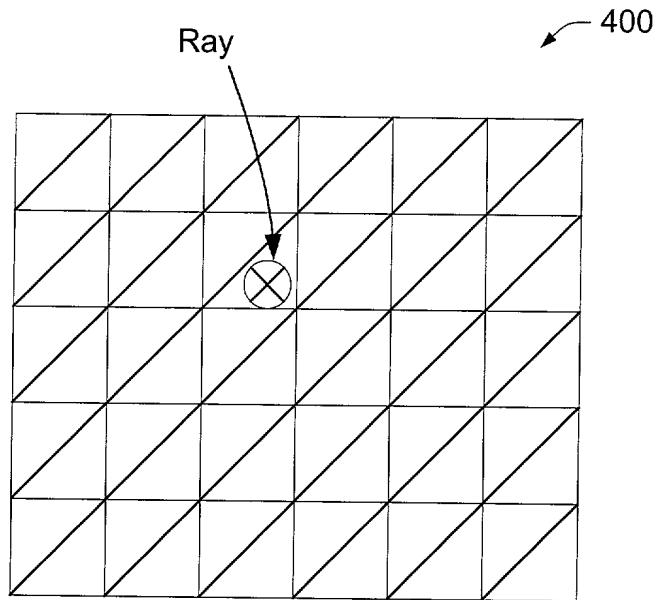


Fig. 7

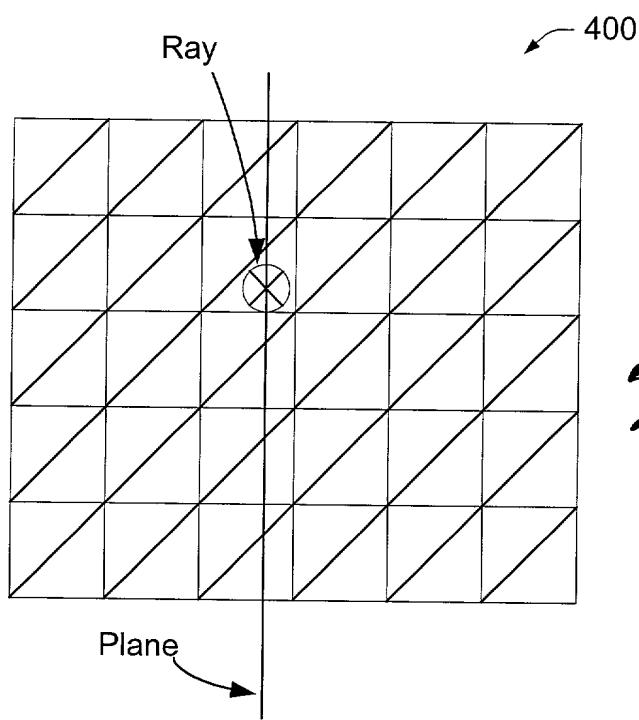


Fig. 8

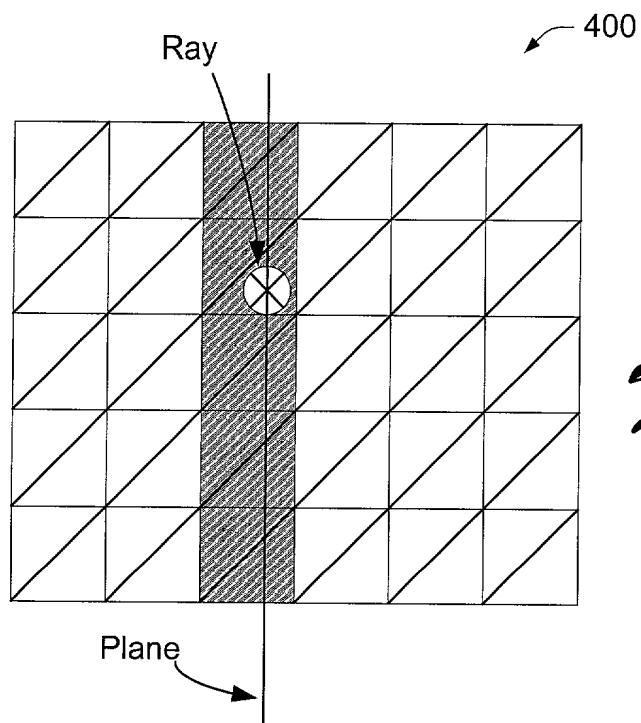


Fig. 9

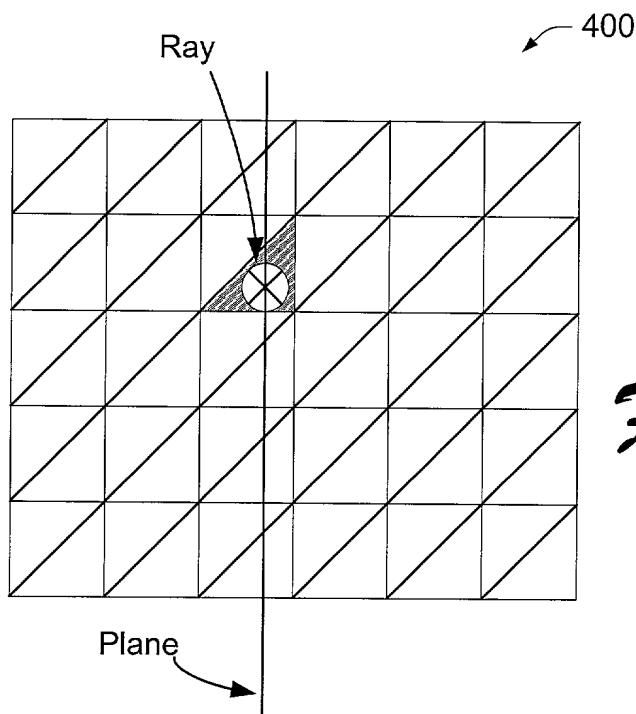


Fig. 10

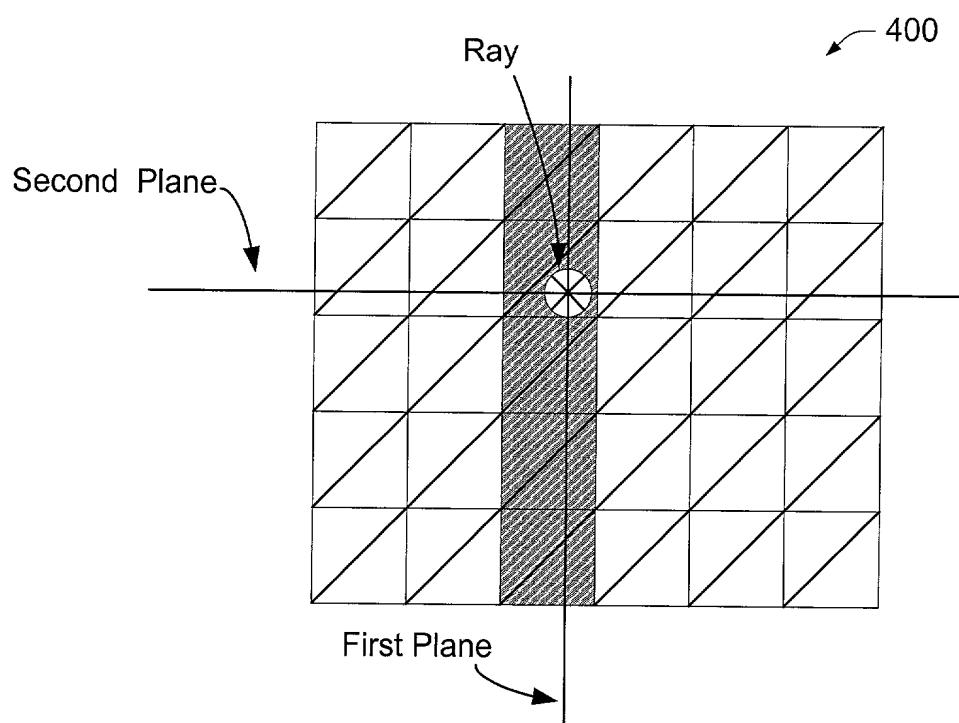


Fig. 11

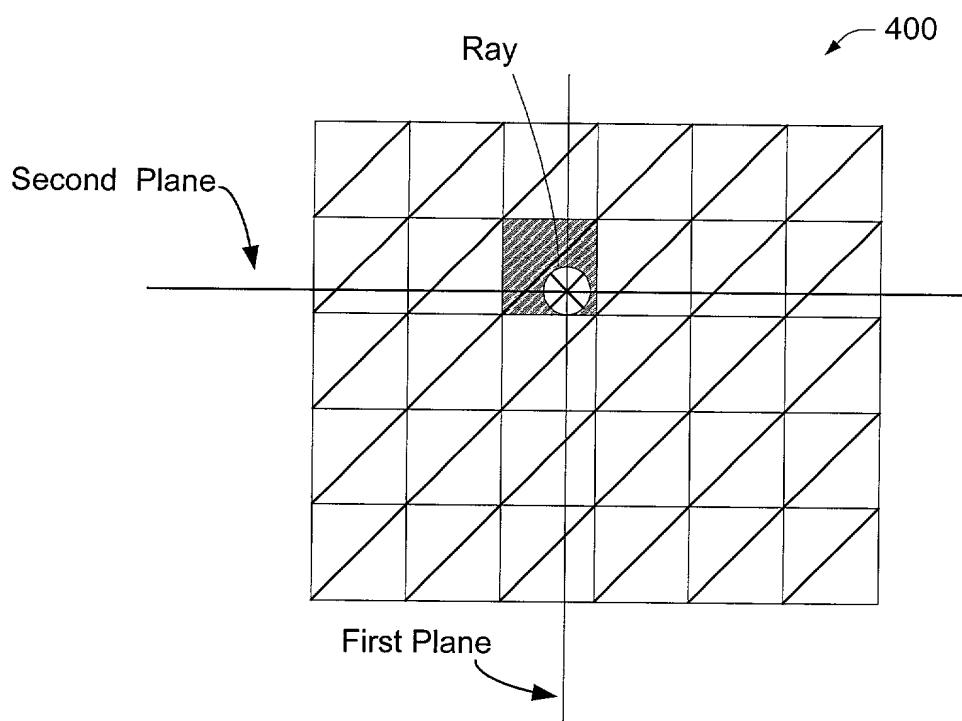


Fig. 12

1                   **IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

2 Inventorship ..... Hollasch  
3      Applicant ..... Microsoft Corporation  
3      Attorney's Docket No. ..... MS1-448US  
4      Title: Methods and Apparatus for Ray Intersection

5                   **DECLARATION FOR PATENT APPLICATION**

6                   As a below named inventor, I hereby declare that:

7                   My residence, post office address and citizenship are as stated below next to  
my name.

8                   I believe I am the original, first and sole inventor (if only one name is listed  
9      below) or an original, first and joint inventor (if plural names are listed below) of the  
10     subject matter which is claimed and for which a patent is sought on the invention  
11     entitled "Methods and Apparatus for Ray Intersection," the specification of which is  
12     attached hereto.

13                  I have reviewed and understand the content of the above-identified  
14     specification, including the claims.

15                  I acknowledge the duty to disclose information which is material to the  
16     examination of this application in accordance with Title 37, Code of Federal  
17     Regulations, § 1.56(a).

18                  PRIOR FOREIGN APPLICATIONS: no applications for foreign patents or  
19     inventor's certificates have been filed prior to the date of execution of this  
20     declaration.

21                   **Power of Attorney**

22                  I appoint the following attorneys to prosecute this application and transact all  
23     future business in the Patent and Trademark Office connected with this application:  
24     Lewis C. Lee, Reg. No. 34,656; Daniel L. Hayes, Reg. No. 34,618; Allan T.  
25

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3 Reg. No. 43,021; Thomas A. Jolly, Reg. No. 39,241; David A. Morasch, Reg. No.  
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6 Suite 500, Spokane, Washington, 99201. Direct telephone calls to: Lance R. Sadler  
7 (509) 324-9256.

8

9 All statements made herein of my own knowledge are true and that all  
10 statements made on information and belief are believed to be true; and further that  
11 these statements were made with the knowledge that willful false statements and the  
12 like so made are punishable by fine or imprisonment, or both, under Section 1001 of  
13 Title 18 of the United States Code and that such willful false statement may  
14 jeopardize the validity of the application or any patent issued therefrom.

15 \* \* \* \* \*

16

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18 Inventor's Signature Stev R Hollasch Date: 24 Nov 1999

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